X-ray Probes of the Universe at Intermediate Redshifts

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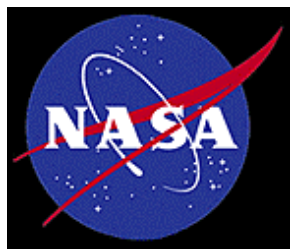
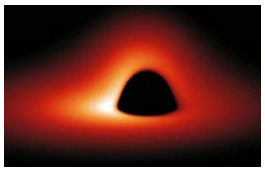


Constellation-X Science Objectives

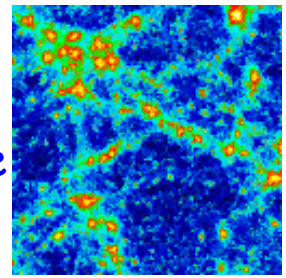
1



Measure effects of **strong gravity** near the event horizon of black holes.

2

Trace baryonic matter throughout the universe and constrain the nature of **dark matter & dark energy**.



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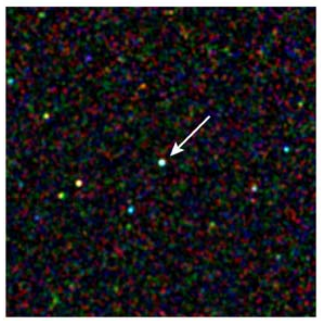


Study formation of supermassive **black holes** and trace their evolution with redshift.

- What roles do they play in galaxy evolution?

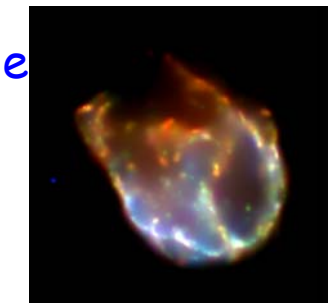
- What is the total energy output of the universe?

4

Study the **life cycles of matter** and energy & understand the behavior of matter in extreme environments.

- What new forms of matter will be discovered?

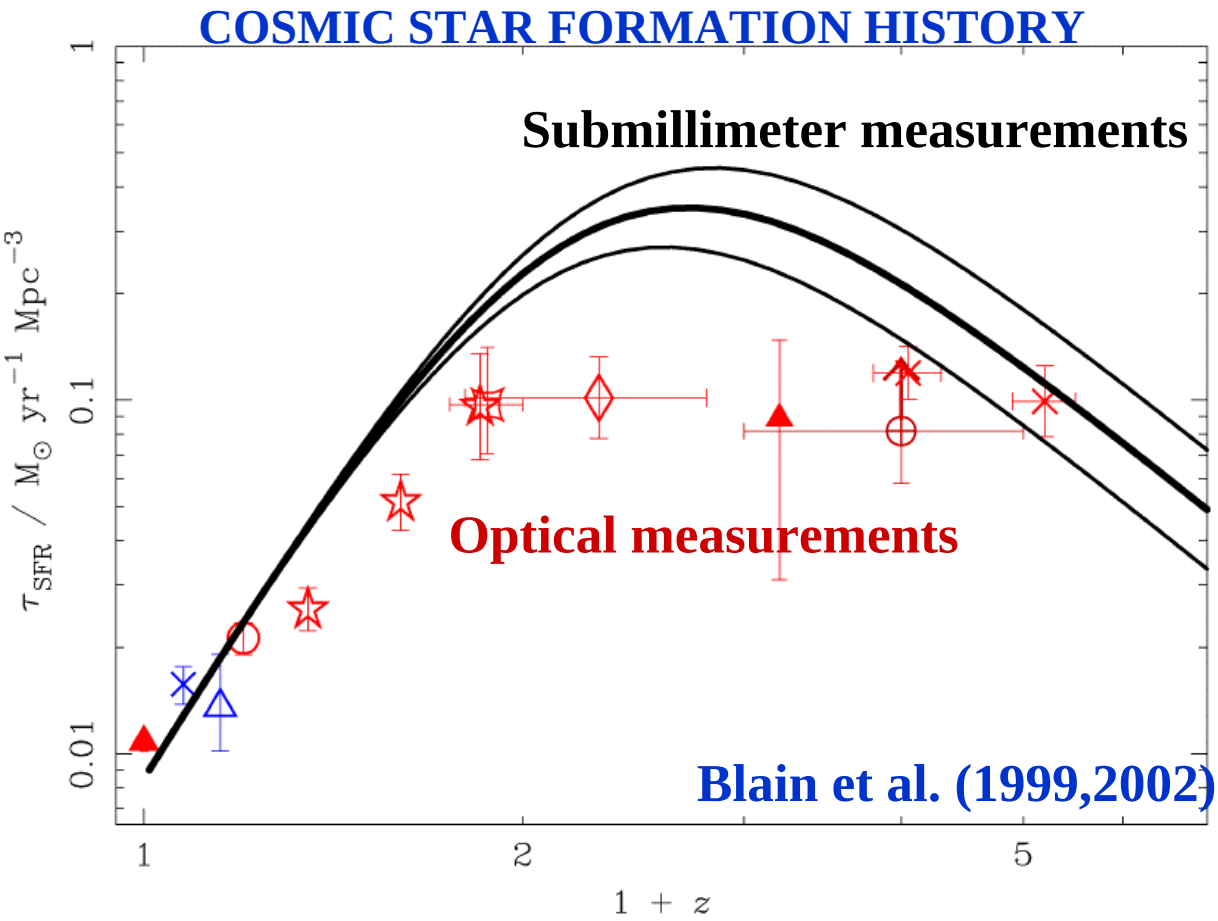
- How does the chemical composition of the universe evolve?



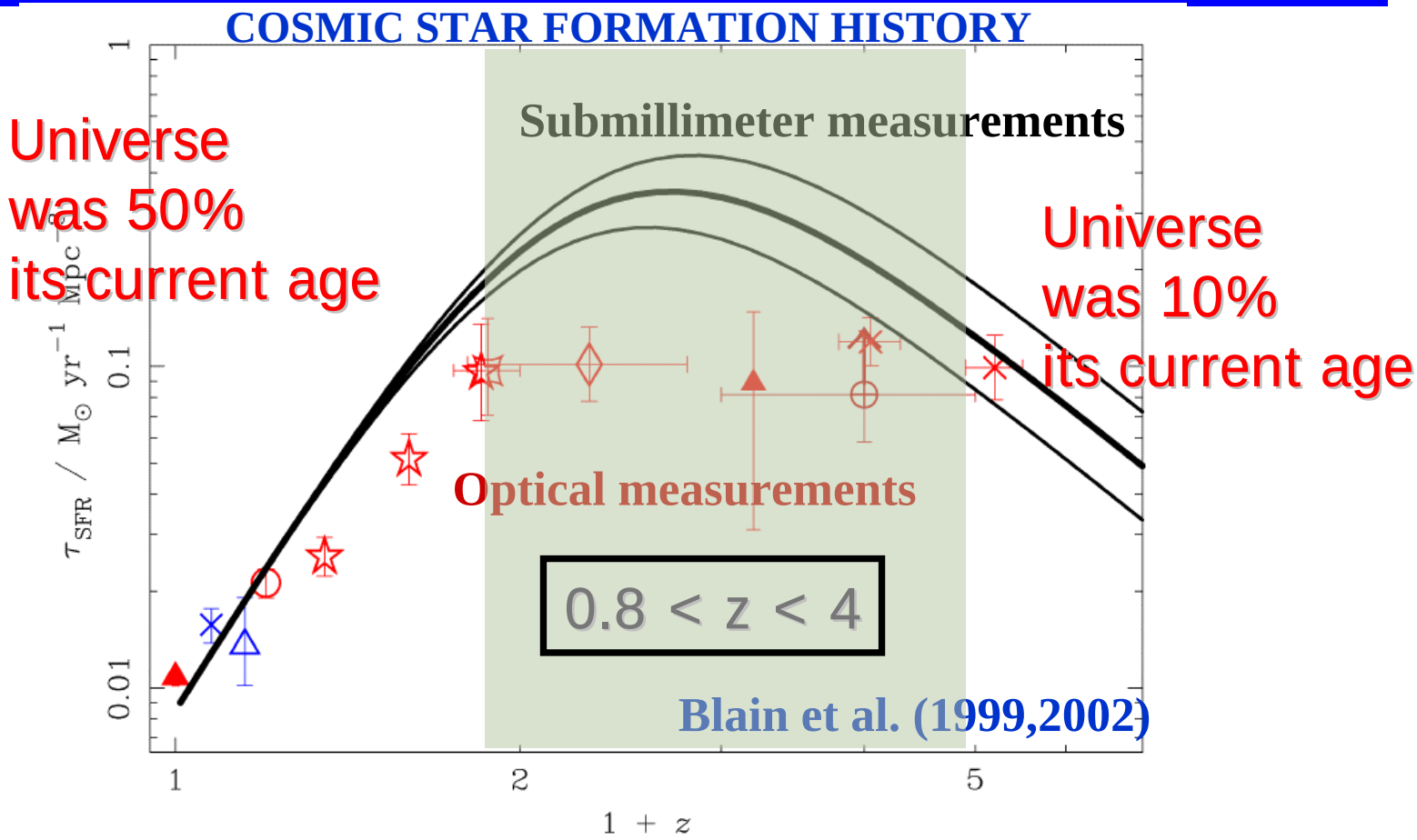
X-ray Probes at Intermediate Redshift

- **Cosmological studies in the X-ray Band**
  - **Life cycles of matter:**
    - **Accreting binary evolution**
  - **Cosmic energy budget**
  - **Role of BHs in Galaxy Evolution (NO TIME)**
- **Observational requirements**

Intermediate redshift??



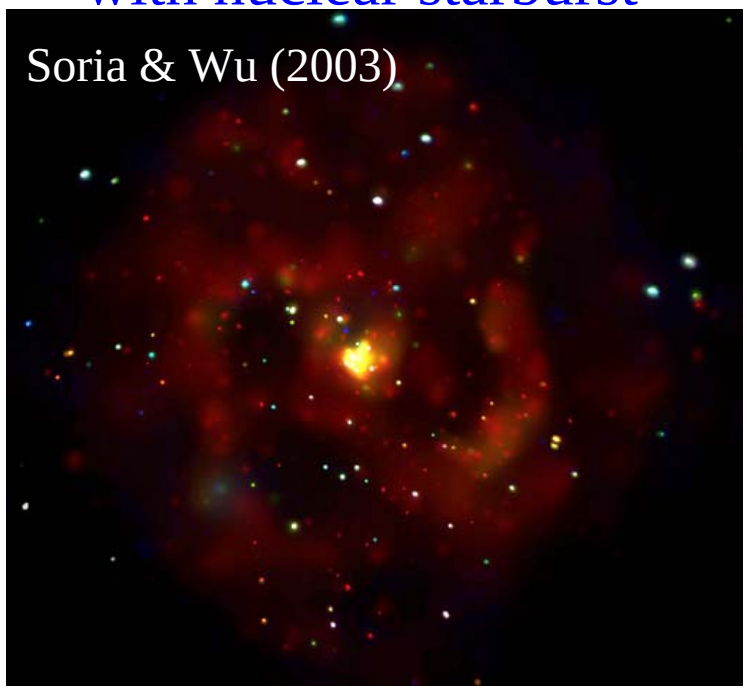
Intermediate redshift??



Life Cycles of Matter

Life Cycles of Matter

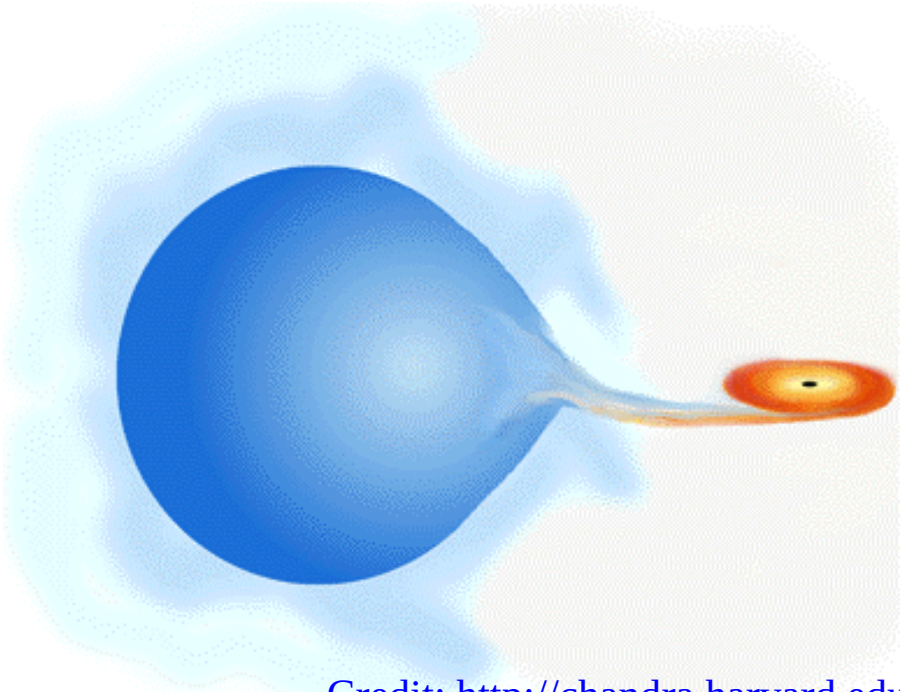
M83, nearby spiral galaxy with nuclear starburst



- **Accreting binaries → high mass end of IMF, emission persists for very long time (Gigayears)**
- **Star formation in heavily obscured areas**
- **Supernovae/winds enrich ISM & IGM, affecting star formation and galaxy evolution**

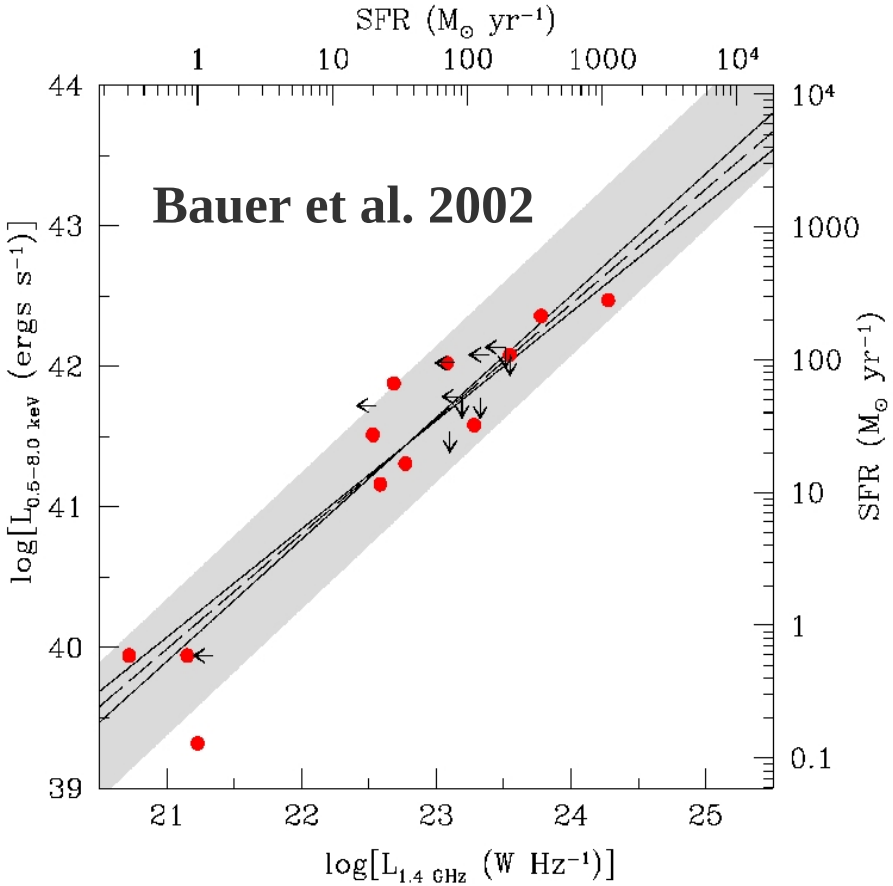
Evolutionary Timescales for X-ray Binaries

- **Mass transfer driven by nuclear evolution of donor**
- **In high-mass X-ray binaries, timescale is approximately ~2-7 × 10^6 yrs (Ghosh & White 2001)**
- **low-mass binaries, this timescale is much longer (> 10^{10} yrs)**



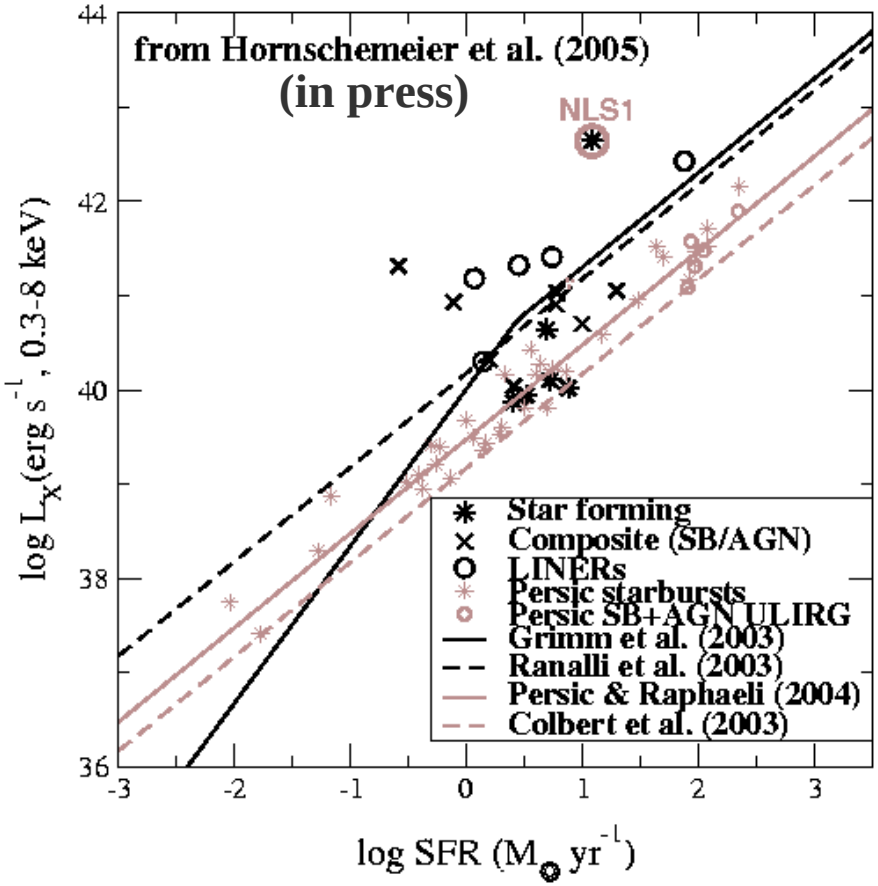
Credit: http://chandra.harvard.edu

X-ray – SFR Correlations



- **0.5-8 keV luminosity appears to be a reliable SFR indicator**
  (Bauer et al. 2002,Seibert, Heckman & Meurer 2002, Ranalli et al. 2002, Cohen et al. 2003)
- **Dominance of accreting X-ray binaries**

X-ray – SFR Correlations

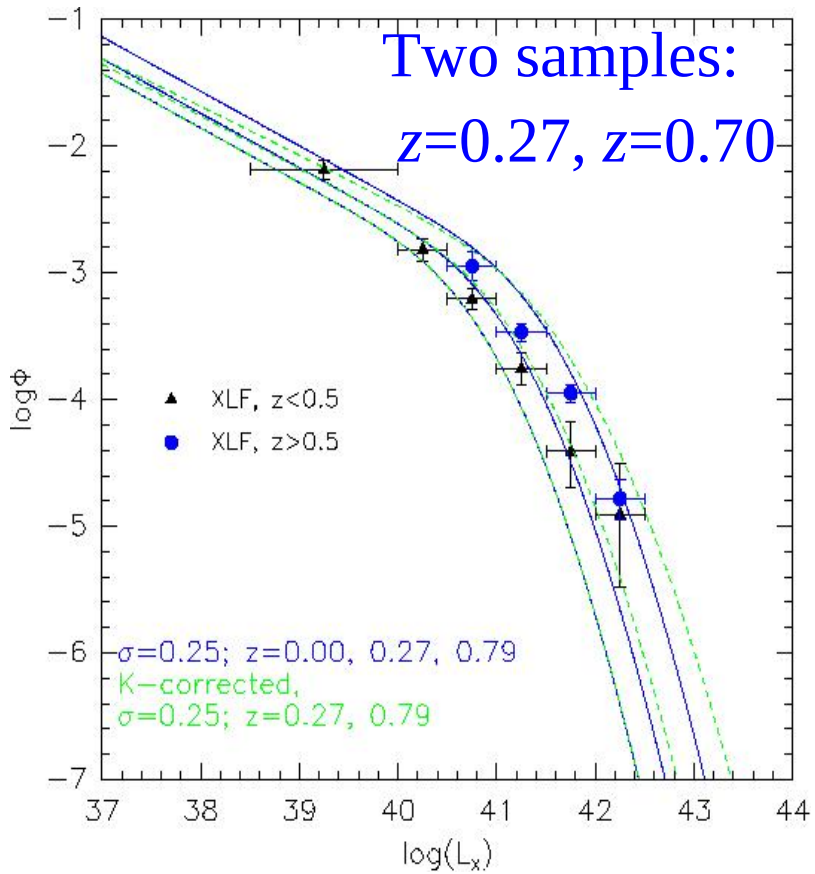


- More than factor of 3 difference in "star formation coefficients"
- Many X-ray components in galaxies may scale with SFR however (hot ISM, AGN activity?): could differentiate with Con-X spectroscopy

Normal Galaxy X-ray Luminosity Functions

- **Evolution consistent with $(1+z)^3$ but…**
- **Conclusions depend on full understanding of L_X-SFR relationship**
- **Evolution of binaries?**

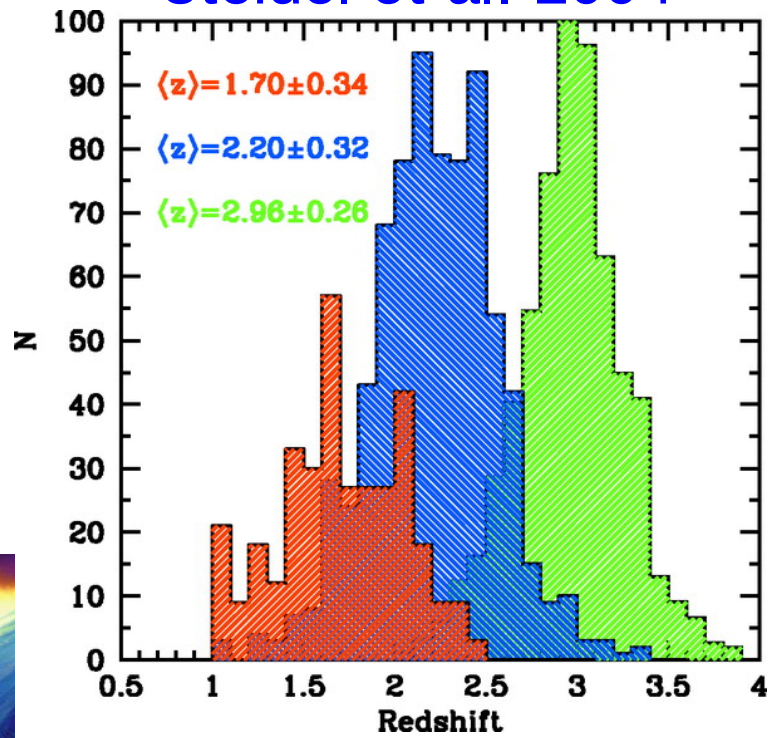
Norman, Ptak, Hornschemeier et al. 2004



X-rays from Star-forming Galaxies at higher z

- **Reddy et al. (2004) find X-ray/SFR relation holds for $1 < z < 3$ galaxies**
- **Lehmer et al. (2005) have stacked 3000 Lyman break galaxies at $3 < z < 6$, find same conclusions about XR-SFR**
- **LOCAL analogs to Lyman Breaks: (Heckman et al. 2005)**

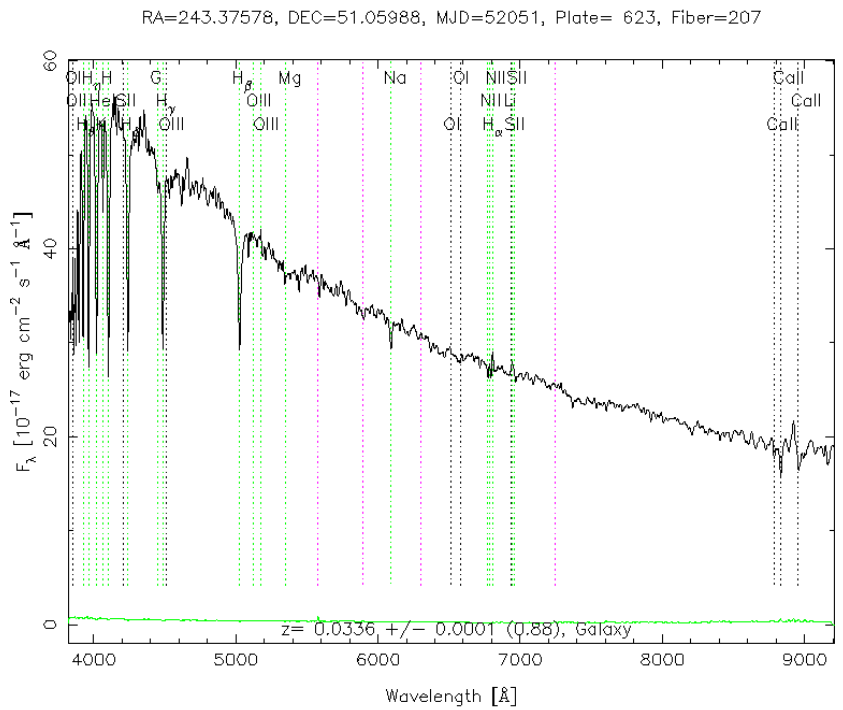
Steidel et al. 2004



X-ray spectroscopy of post-starburst galaxies

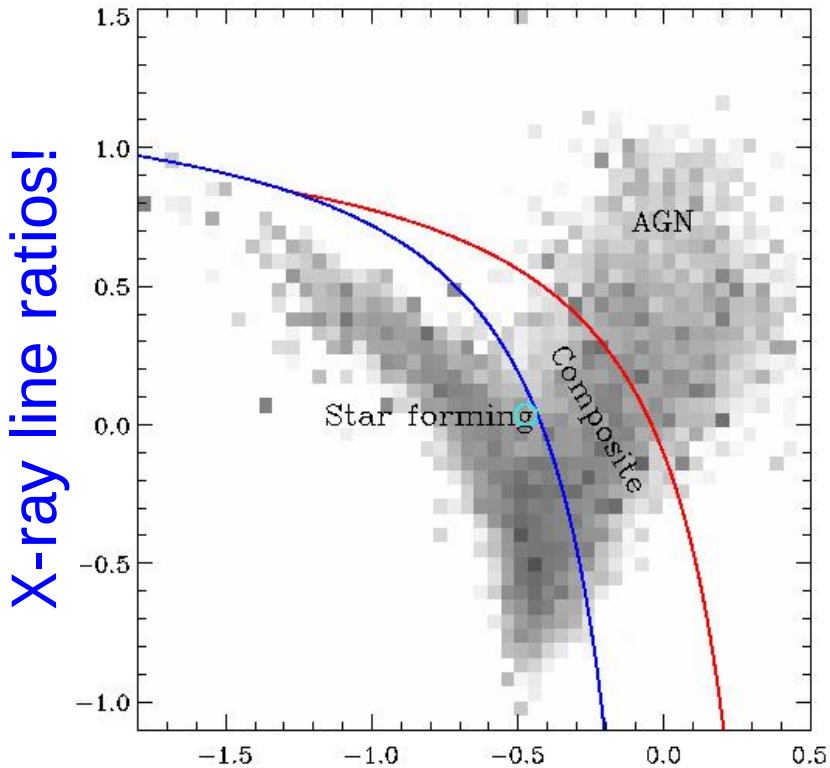
- **Just beyond the reach of current X-ray CCD spectroscopy**
- **X-ray binary stellar synthesis models (e.g., Belczynski et al. 2004, Sipior et al. 2005) agree with inferred burst mass fractions and ages in these galaxies (Hornschemeier et al. 2005)**
- **May have a tool such as STARBURST99 (Leitherer et al.) for the X-rays by 2010**

Goto et al. (2003), Post-starburst Galaxy



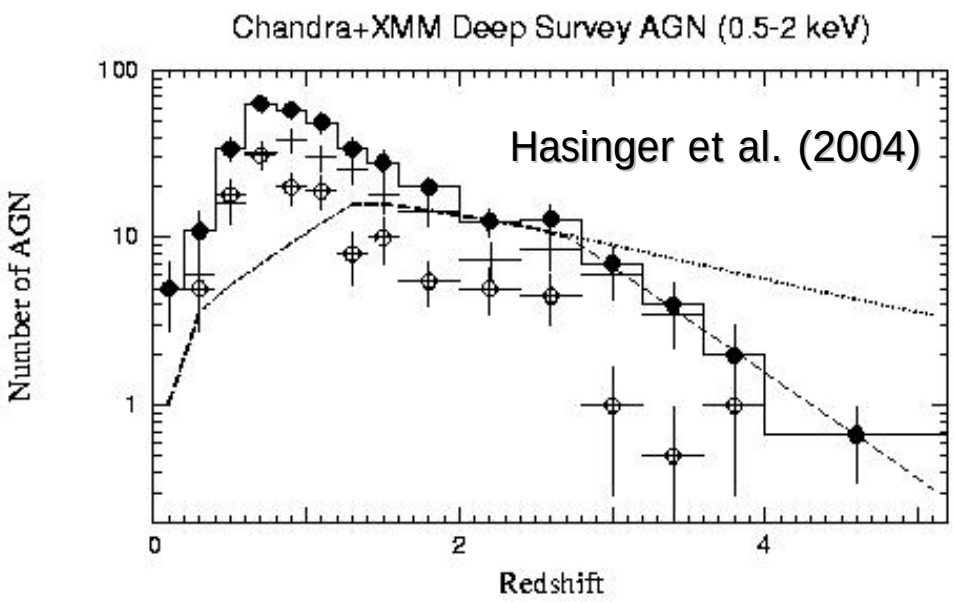
X-ray spectroscopic diagnostics of galaxies

SDSS "BPT" Diagram from Brinchmann et al.



Total Energy Output of the Universe

X-ray Emission from the Universe



Contributors to the 2-10 keV XRB

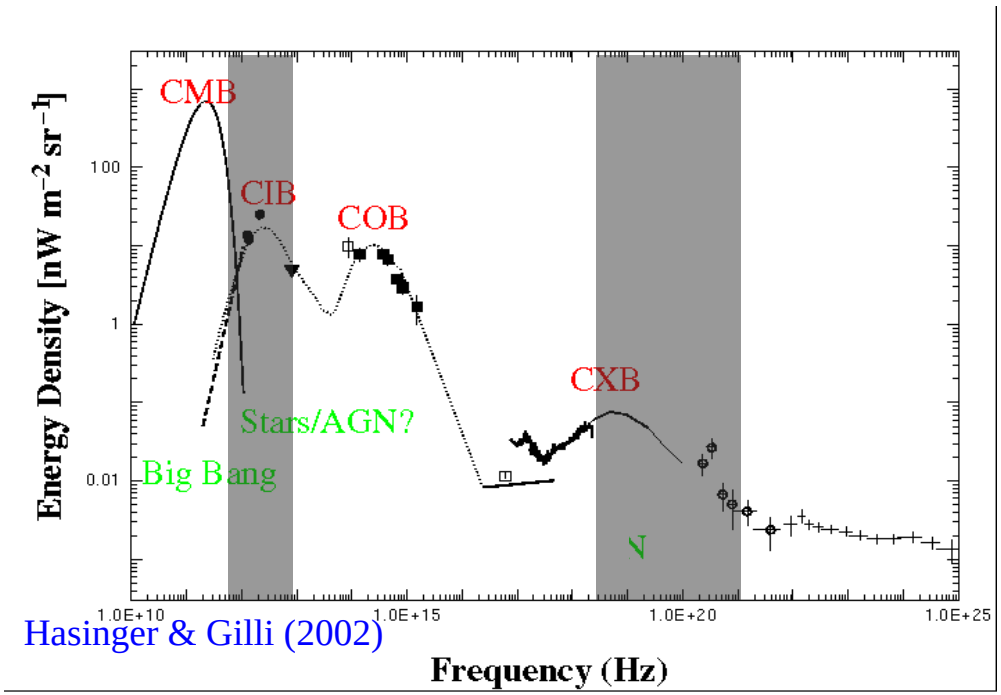
(Hornschemeier et al. 2003, Moretti et al. 2003, Bauer et al. 2004)

- **X-ray obscured AGN: 45%**
- **X-ray unobscured AGN: 38%**
- **Galaxies: 3%**
- **Clusters: ~5%**

TOTAL: 91%

The high-energy Universe is dominated by accreting supermassive black holes at intermediate redshift

Extragalactic Background Radiation (EBR) Studies



Hasinger & Gilli (2002)

- **Observationally elusive for the longest time: hard X-rays and submm**
- **Submm counterparts often optically faint (I>24), VERY difficult to ID with optical spectra**
- **X-ray identification rate much better, find AGN aren't dominating submm emission (Alexander et al. 2003)**

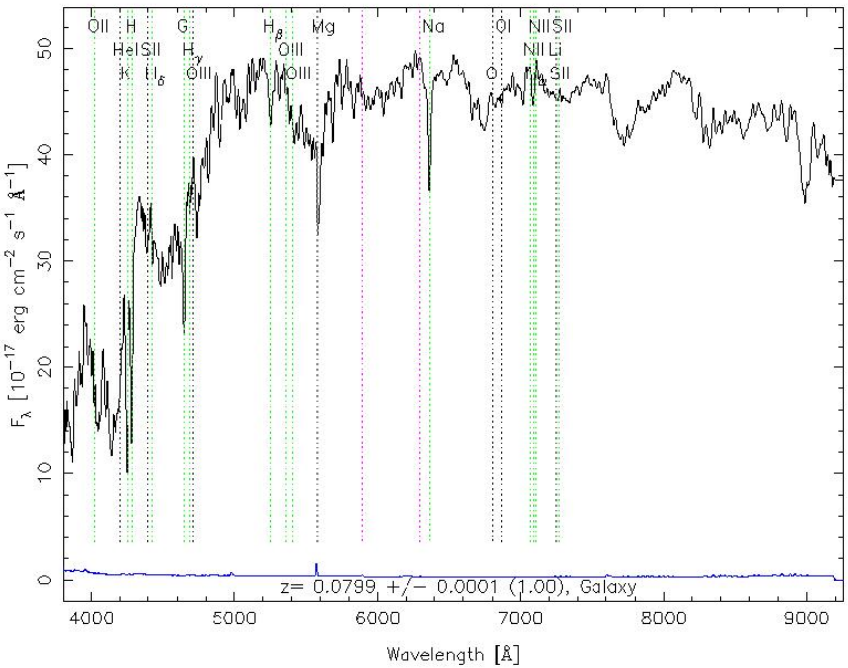
EBR Studies: Remaining items

- **40 keV background? (HXT!)**
- **Are Chandra & XMM are missing *highly* obscured AGN? …might be found in e.g., *Spitzer* surveys (Treister et al. 2005)**
- **X-rays are most feasible way to identify the physics of the submillimeter sources**
  →*constraining >90% of the energy production of the Universe…*

Con-X Spectroscopy of Elusive AGN

- **``Elusive" AGN (e.g., P3, Comastri et al., Fiore et al.)**
- **Plausibly an optical aperture effect (Moran et al. 2003, Hornschemeier et al. 2005)**
- **May be a class of accreting SMBH that is missed in optical surveys → X-ray spectroscopy alone will reveal the nature of these objects**

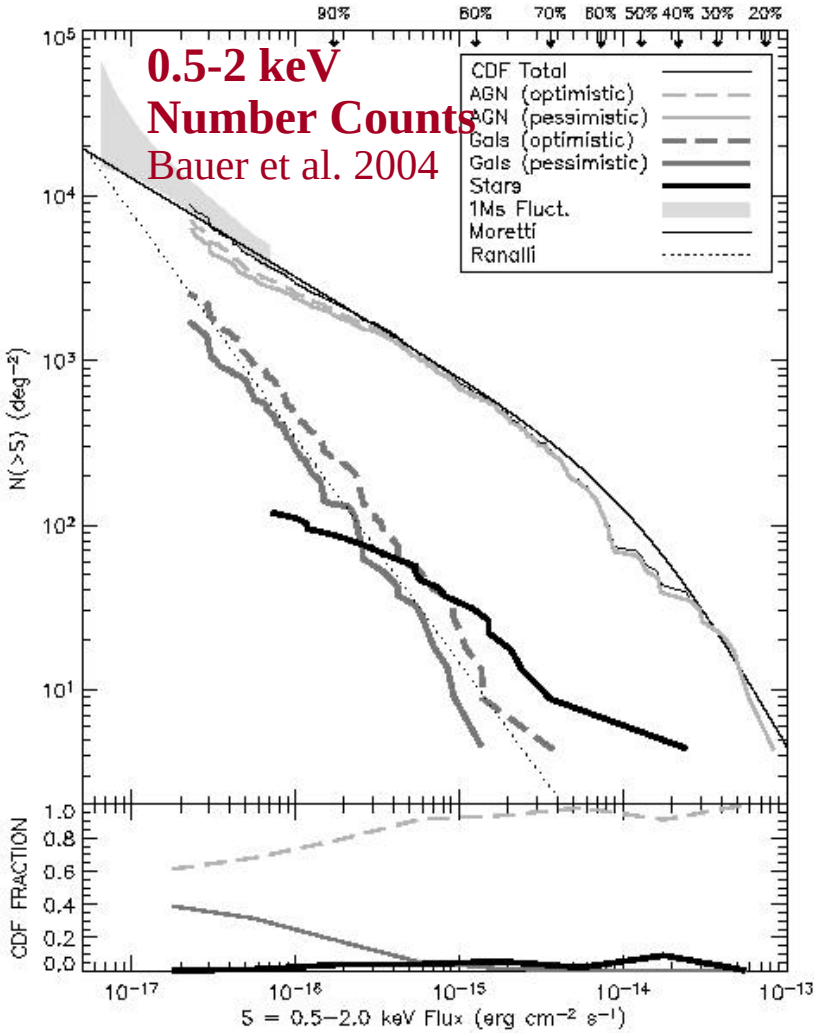
SDSS Spectrum of
X-ray Luminous Galaxy
(Hornschemeier et al. 2005)



Observational Requirements for Intermediate-Redshift Studies

- **X-ray flux of typical X-ray obscured submm source: ~1 × 10^{-16} erg cm^{-2} s^{-1} (0.5-2 keV)**
- **X-ray flux of 10^{42} erg/s Seyfert galaxy at z~1: ~2 x 10^{-16} erg cm^{-2} s^{-1} (0.5-2 keV)**
- **X-ray flux of star-forming SDSS galaxy at z~0.1: <2 x 10^{-16} erg cm^{-2} s^{-1}**
- **Spatial resolution? Not essential at these redshifts (rely on Chandra IDs in some cases)**

What if you put an WFI behind this large X-ray mirror?



- **CONFUSION: Typical optical magnitudes of AGN at fluxes < 1 x 10^{-17} erg cm^{-2} s^{-1} (0.5-2 keV) requires spatial resolution < 1.6”**
- **Hitting X-ray confusion around 2”, 5 x 10^{-18}**
- **WFI not so useful for higher-z science at 5”-10” planned spatial resolution**

Coming soon

- New science panel to cover this topic, evaluate what is/is not accessible with Con-X
- Higher-z science available to Con-X but may rely heavily on existing Chandra/XMM surveys
- Galaxy surveys such as SDSS, GALEX provide excellent samples for projects relevant to life cycles of matter but would be “snapshot” programs to be effective
- and finally….

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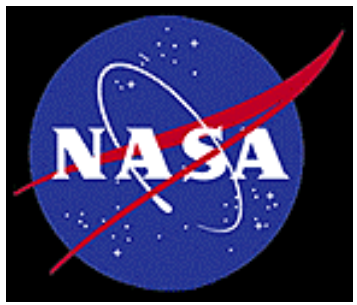

Coeval Growth of SMBH and Galaxy Bulges

- **Bulge mass-BH relationship → SFR in spheroids expected to be found around luminous (i.e., *growing*) SMBH**
- **Based on standard assumptions, the ratio of starburst to AGN emission is a factor of ~5 (Page et al. 2000)**
- **Initial results by Page et al. 2004**
  - **X-ray unobscured QSOs→ not submm emitters**
  - **X-ray obscured QSOs: → strong submm emitters**
  - **Proposes that the largest SMBH are X-ray obscured QSOs for 15% of their lives**